

Widening the perspective in greenhouse gas emissions accounting: The way forward for supporting climate and energy policies at municipal level

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ABSTRACT

The transition towards low-carbon economy requires a number of specific actions by a multiplicity of actors in order to reduce greenhouse gas (GHG) emissions, entailing energy efficiency, production of energy from renewable resources as well as the diffusion of more sustainable production and consumption patterns. Among the actors, local authorities can play a leading role for climate action. However, properly accounting for GHG emissions at local scale and identifying actions for GHG reduction are still an open challenge in many contexts. In this paper, we propose a method for GHG emissions accounting to support the identification of proper actions to achieve GHG reduction targets. The method widens the classical production-based approach to accounting, by proposing an extension of the accounting to three main areas: waste management and recycling, consumption patterns, and local land management. Life cycle thinking is applied as methodological basis for such extension. To illustrate the benefit of the proposed approach, the method has been applied to 16 municipalities (in Northern Italy), which were signatories of the Covenant of Mayors (CoM) initiative. CoM is a European initiative by which local authorities voluntarily commit to reduce their GHG emissions through the implementation of Sustainable Energy Action Plans. A comparison of the emission profile of the different municipalities helps identifying common patterns and local peculiarities to be addressed to achieve the reduction target. For the analysed case studies, the biggest contribution to GHG emissions comes from the consumption of the natural gas and electricity by the household sector. Emissions from waste generation play a minor role in the selected case studies. However, the inclusion of avoided emissions coming from waste recycling highlights the reduction potential if an appropriate waste management system is in place. Consumption patterns, as well, may play a relevant role. For example, assessing GHG emissions related to food consumption on top of those due to other drivers, the total municipal emissions change by increasing for an average of 22.6% for the selected case studies. Moreover, local land use planning and management should be included in the assessment, being crucial not only for the emissions uptake but also for climate mitigation and adaptation. The proposed approach to GHG accounting, including consumption-based aspects, may help identifying a wider set of climate actions to be implemented by local authorities to reduce environmental burdens.

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1. Introduction

“Before the Industrial Revolution in the 19th century, global

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average CO₂ was about 280 ppm. During the last 800 000 years, CO₂ fluctuated between about 180 ppm during ice ages and 280 ppm during interglacial warm periods. Today's rate of increase is more than 100 times faster than the increase that occurred when the last ice age ended” (NOAA, 2013). Greenhouse gases (GHG) (such as: CO₂, CH₄, N₂O, CFCs, etc.) affect climate change strengthening the *greenhouse effect*. They are also measured as equivalents of CO₂, on the basis of their Global Warming Potential (GWP). Combustion processes for energy generation, mobility, heating, as well as

electricity consumption largely affect the GHG emissions (EEA, 2013a). Increasingly, the role of consumption patterns of energy and good is recognised as a key element to be addressed (Notarnicola et al., 2017). In Europe, the growth in GHG emissions calculated with consumption-based approaches contrasts with the decreasing trends for EU emissions calculated using production-based ones (EEA, 2017). For this reason, the energy planning and policies should be complemented with consumption-oriented considerations in order to better support climate policies.

Since the 70s, the United Nations has undertaken many international initiatives to tackle climate change. A milestone in these regards was the Kyoto Protocol, an international agreement linked to the United Nations Framework Convention on Climate Change, which committed its Parties (Countries) by setting internationally binding emission reduction targets (UNFCCC, 2005). At the end of 2012 the Protocol have been extended through the Doha Amendment (UNFCCC, 2014), and Post-Kyoto commitments have been framed within the Paris Agreement of 2015 (UNFCCC, 2015), which is a legally binding agreement between Parties (197 Countries) for climate change, including mitigation and adaptation. The agreement recognizes the role of non-signatory entities as regions, cities, and local authorities in addressing climate change.

At the European level, the EU Climate and Energy package (European Commission, 2010a, 2008) aimed at developing a low-carbon economy, and fixed targets for: i) increasing the share of energy produced from renewable resources; ii) decreasing the GHG emissions; and iii) improving energy efficiency. The 2030 climate and energy framework updates key targets for the year 2030 and builds on the 2020 climate and energy package. The envisaged “climate action” (European Commission, 2014) sets three key targets for the year 2030: i) at least 40% cuts in greenhouse gas emissions (from 1990 levels); ii) at least 27% share for renewable energy; and, iii) at least 27% improvement in energy efficiency.

Globally, local authorities play a key role in the achievement of the energy and climate objectives. At European level, since 2008, a specific initiative for involving local authorities in achieving GHG reduction has been promoted: the Covenant of Mayors (CoM) initiative (European Union, 2017). CoM initiative has been originally defined in order to support local authorities which voluntarily commit to reduce their GHG emissions beyond the 20% target (European Commission, 2010b). At the end of 2017, the initiative involves more than 7700 local and regional authorities going beyond EU (across 57 countries) and resulting in a worldwide multi-stakeholder movement (European Union, 2017). One of the peculiarity of the CoM initiative is the broad involvement of small municipalities in the effort to reduce GHG emissions. Indeed, small and medium municipalities are representing more than 80% of the total number of signatories of the initiative (Kona et al., 2015).

When the CoM initiative was launched, the minimum commitment was to reduce the level of emissions by 20%. The first CoM signatories had estimated for 2020 an overall reduction of 28% of the GHG emissions in comparison with the reference years (Kona et al., 2015). Nowadays, new signatories are committed to reduce CO₂ emissions by at least 40% by 2030 and to adopt an integrated approach to tackling mitigation and adaptation to climate change.

From the geographical point of view, the initiative has been successful especially in the Mediterranean Europe, since “the Country with the biggest number of inhabitants involved in this action is Italy (30 million inhabitants), followed closely by Spain (24 million inhabitants)” (Cerutti et al., 2013).

Key element to define climate actions and plans is a comprehensive analysis of the actual situation of GHG emissions, including sectors, carriers, and vectors that cause the GHG emissions. Building from the GHG emission accounting, Sustainable Energy Action Plans (SEAPs) may be defined, namely identifying concrete

reduction measures, together with time frames and assigned responsibilities, which translate the long-term strategy into actions. CoM initiative concerns mainly actions at local level within the competence of the local authority, defining measures aimed at reducing the GHG emissions and final energy consumptions by end users. The CoM's commitments cover the whole geographical area of the local authority. Therefore, the action plans should include actions concerning both the public and private sectors (European Commission, 2010b).

In the context of the Covenant of Mayors, the Baseline Emission Inventory (BEI) is defined as the quantification of the amount of GHG emitted due to energy consumption in the territory of a Covenant signatory within a given period of time (European Commission, 2010b). The BEI allows identifying the principal sources of GHG emissions and their respective reduction potentials. Local authorities should use the results of the BEI to identify the best areas of intervention and opportunities for achieving GHG reduction target. In order to help local authorities developing their emission inventories and designing their own action plan, the guidelines for the Covenant of Mayors have been evolving over time, towards inclusion of additional aspects, e.g. related to climate change adaptation and mitigation (Neves et al. 2016). However, the original focus of the GHG accounting has been mainly production-based.

However, three broad consumption categories — housing and utilities, mobility, and food — account for approximately half of European household expenditure and more than two-thirds of the direct and indirect environmental pressures caused by household consumption (EEA, 2013a,b). Consumption-based approaches to GHG accounting has been already extensively discussed in literature, including the analysis of the possible link with local authority socio-economic structure (Larsen and Hertwich, 2010). Hence, besides what already is included in BEI (namely housing and mobility), it could be important to include other drivers of consumption-based emissions.

In this paper, we propose an extended GHG emission accounting method which is including additional perspective in the accounting, building on generally available data, needing limited data collection but still capable to provide useful insight for action planning. The proposed method aims at addressing several drivers of emissions, related to a different policies at local scale (energy, waste, land use planning, sustainable production and consumption), highlighting their relevance in terms of GHG emissions. Hence, the method includes the sectors inventoried in the CoM, plus an additional estimation of GHG emissions avoided through: recycling of waste (relevant for including aspects related to e.g. circular economy), land use planning, and consumption of goods (relevant for addressing broadly the production and consumption patterns).

Specifically, the method has been tested on 16 municipalities of Lombardy Region which adhere to the CoM in 2010 (Fondazione Idra, 2011). This formal commitment was accompanied by the proposal of a SEAP, describing the emission reduction actions planned by the local authorities and to be achieved by 2020.

2. Materials and methods

Approaches to GHG accounting for local authorities can be different. For example, EEA (2013b) identifies three accounting perspectives, with reference to the scope of the emission inventory of a defined geographical area:

- **Territorial perspective.** Emissions are accounted for when emitted within the local authorities boundaries (being a country, region, municipalities). At country level, this is the only

method accepted by international environmental law, and adopted by the Intergovernmental Panel on Climate Change (IPCC) to account for a country's emissions and mitigation efforts (Bastianoni et al., 2014).

- **Production perspective.** Emissions are accounted for e.g. from companies that have their economic interest within the economic territory of the local authority. It also considers emissions from resident households in relation to their productions, irrespective of the geographic location where these activities take place.
- **Consumption perspective.** Emissions are accounted for in relation to consumption of goods and services within a local authorities boundary, irrespective of the geographic location where production of these goods and services result in direct emissions. The consumption perspective complements the territorial accounting and the production perspective by relating environmental impacts to demand for goods and services by citizens. The consumption-based perspective is not addressed in international conventions, although consumption emissions are embedded in the EU's policy framework on sustainable production and consumption.

The emission accounting at municipal level usually considers as system boundaries the municipal administrative boundaries. However, a significant flow of goods and services happens across municipalities and many infrastructures have cross-administrative boundaries. At the city scale, accounting approaches may be categorised as follows (Ramaswami et al., 2011):

- **Purely geographic production-based GHG accounting.** It corresponds to the *territorial perspective* described in (EEA, 2013b).
- **Geographic-plus infrastructure supply chain GHG footprints.** This approach has been defined for GHG accounting for cities. It considers materials and energy from energy and infrastructure supply chains (e.g., electricity production or waste treatment plants) used by cities but located outside the city boundaries (Yetano Roche et al., 2014)
- **Pure consumption-based accounting.** It corresponds to the *consumption perspective* described in (EEA, 2013b).

Ramaswami et al. (2011) highlight that geographic-plus and consumption-based approaches can provide different sets of useful insights on drivers of GHG emissions. In other words, ideally, the GHG emissions at municipal scale should be calculated on the basis of the consumed energy and materials by different sectors (household, industry, agriculture, transport, services) that (economically) happen within the municipal borders, including the consumption perspective (Larsen and Hertwich, 2009).

2.1. Methodology for extended municipal GHG emissions accounting

The developed methodology complements a territorial-oriented approach with consumption-oriented aspects. The CoM inventories are mainly focusing on final energy consumption related to two main macro-sectors: “buildings, equipment/facilities and industries” and “transport” (Neves et al. 2016). In this study, the GHG accounting as proposed by the CoM is complemented with: i) avoided emissions due to waste recycling; ii) estimations related to the consumption of food; and, iii) inclusion of land use aspects. The added aspects are meant at this stage only for screening purposes. However, they may help understanding the potential relative relevance of their inclusion.

The BEIs of the 16 Italian municipalities, selected as case study, are available on the official website of the CoM (European Union,

2017), within their SEAPs. Details on the local authorities are reported in section 2.2. Regarding the reference year, the CoM approach recommends 1990 as baseline for the BEI. However, if the local authority does not have data to compile an inventory for 1990, then it should choose the closest subsequent year for which the most comprehensive and reliable data can be collected (Bertoldi et al., 2010). Hence, for this case study, the year 2005 has been chosen as reference year for calculating the BEI, due to the data availability and to allow comparison with most recent year. According to (Kona et al., 2015) most of the signatories decided to take 2005, or 2007, or 2008 as their reference year.

To ensure actions for different sectors, different “emission drivers” have been identified and the Municipalities have been advised to define their final objective of GHG reduction addressing them, namely:

- **Municipality's.** This category considers the GHG emissions caused by the activities directly related to public buildings. Fixing a reduction objective for this category will ensure the direct commitment of the Municipality for emission reduction.
- **Energy consumption (no electricity).** This category considers the GHG emissions caused by consumption of fuels. Fixing an objective for this category could lead in taking action in household, transport and industry/tertiary sectors. Especially, the reduction of natural gas consumptions in household sector can play a crucial role for reducing emissions from energy consumptions. In fact, household sector covers about 40% of the GHG emissions from energy consumptions of the Lombardy Region in 2005, and natural gas is responsible of about 72% of the GHG emissions from energy consumption of the household sector of the Region (SIRENA, 2014). Additionally, partitioning the overall objective in “transport” and “other sectors” may lead to identify action involving different sectors and actors to achieve the commitments.
- **Electricity consumption.** This category considers the GHG emissions caused by consumption of electricity. Improving the energy efficiency and increasing local production of electricity from renewable resources are the cornerstones to reduce emissions from electricity consumptions.
- **Waste production and recycling.** This category considers the GHG emissions caused by waste management. In this study we complement this with avoided emissions due to the separate collection. Keeping separated this category ensures to plan actions focusing on waste generation and management, leading to possible additional benefits to the SEAP.
- **Food consumption.** Given the relevance of food consumption as driver of GHG emissions, a calculation of the emission related to this has been added.

The CoM approach considers the administrative boundaries of the local authority as the geographical boundaries of the BEI. The baseline GHG inventory was based on final energy consumption, including both municipal and non-municipal energy consumption in the local authority's territory. The following emissions were quantified: i) direct emissions due to fuel combustion in the territory in the buildings, equipment/facilities and transportation sectors; ii) (indirect) emissions related to production of electricity, heat, or cold consumed in the territory; iii) other direct emissions that occur in the territory, depending on the choice of BEI sectors (e.g. waste collection within the city boundaries). It has to be noted that all emissions are accounted but the industrial ones included in Emission Trading Scheme (ETS). Being subject to a specific approach to emission reduction, ETS emissions are excluded from the CoM accounting.

Specifically, the presented methodology estimates the GHG

emissions by energy and goods consumed within the municipal territory (Fig. 1). The energy consumptions are obtained by available data: either local, regional or national. Data on generation of renewable energy are as well retrieved from national and local databases. The methodology applies emission factor-based calculations, and GHG emissions are calculated by multiplying activity data and emission with the corresponding factor, which is specific for each energy carrier. Activity data (such as electricity consumed in municipal buildings in MWh, or heat consumed by residential buildings) quantify the human activity occurring in the territory of the local authority (Bertoldi et al., 2010). Emission factors are coefficients, which quantify the emission per unit of activity. Examples of emission factors are: amount of CO₂ emitted per MWh of oil consumed in t CO₂/MWh_{fuel}, or amount of CO₂ emitted per MWh electricity consumed t CO₂/MWh_e. For instance, in order to account for the overall emissions of municipal buildings, it is necessary to follow these steps: i) listing the relevant buildings to be included in the accounting; ii) gathering data for yearly electricity and heat consumption in the buildings; iii) calculating GHG emissions by multiplying the electricity and heat consumption with their specific emission factors; iv) aggregating the final result at building level and at the entire municipal building stock level. Further details about the different steps involved in the proposed methodology are reported hereinafter.

2.1.1. GHG emissions associated to overall municipal energy consumption

Available data, as from national and sub-national databases, can be used to quantify energy consumptions, with limited costs and administrative burdens, especially for small municipalities.

Since 2007, SIRENA (Regional Informative System for Environment and Energy) provides data on fuel consumption, production and transmission/distribution of electricity for the Lombardy region (Italy). SIRENA is a web-based service supplying energy-related information that, at different territorial levels, allow delineating the energy dynamics of Lombardy (SIRENA, 2014). SIRENA represents the main data source for calculating the BEI of

Lombardy municipalities, entailing statistics on energy consumption by sectors of use (Households, Non-ETS Industry, Urban Transports, Tertiary/Services, Agriculture) and by energy carriers (biomass, natural gas, petrol, diesel, electricity, other fuels).

The methodology for calculating energy consumptions in SIR-ENA database is described in (Boccardi et al., 2012). The methodology is based on the effective consumptions of energy within the municipal boundaries. However, disaggregation from Provincial or Regional level is needed for accounting all the consumptions. For example, consumptions of transport sector are based on data detailed at municipal level and data at other scales in order to account for road infrastructures that cross the municipality (municipal roads, state highways and railways) as reported in Boccardi et al. (2012).

Local authorities are expected to play an exemplary role and, therefore, to take outstanding measures related to the local authority's own buildings and facilities. A separate accounting for energy consumptions and related GHG emissions of Municipality buildings is then foreseen.

In order to define effective actions for reducing the GHG emissions, a good knowledge of *how much* has been emitted is not enough: the decision makers should know also *which* are the main sources of emissions. Therefore, data on energy certifications of buildings, heating plants and boilers (number and typology), vehicle fleets should be collected. This information is defined as “support data”, giving an overview on the performance of different sectors in terms of emission and energy efficiency.

An overview of the data used for calculating the BEI is given in Table 1.

The emissions related to the energy consumptions are derived from all energy carriers and include the share of imported electricity. Table 2 shows the Emission Factors considered for the different energy carriers. Emission factors are calculated according to the IPCC methodology (IPCC, 2006), converting GHG emissions into equivalents of carbon dioxide (CO_{2EQ}). The emission factors are reported referring to 100 year time horizon.

The Emission Factor related to electricity production is defined by (Italian Ministry of Environment, 2012) as an average value related to the Italian energy mix.

For what concerns the electricity generation at local level, generation from photovoltaic (PV) plants was included in the accounting, assuming a substitution of the energy distributed by the national grid. On the basis of the installed capacity it is possible to estimate the energy production, and, consequently, the avoided GHG emissions. The equation that has been used is (Fthenakis et al., 2008):

$$AE = C \cdot 1100 \cdot 0.531 \quad (1)$$

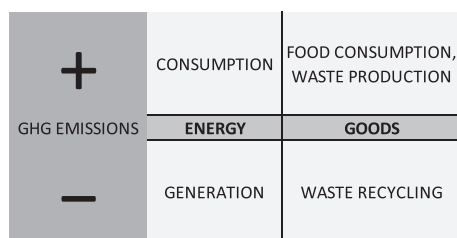


Fig. 1. Scheme for calculating the baseline emission inventory. For this study, the generation of energy is intended as the production of renewable energy.

Table 1

Data for defining the Baseline Emission Inventory and sources used for the case study.

Data	Source
Energy consumption by vector	Regional data (www.sirena.cestec.it)
Renewable energy production	Atlas of photovoltaic plants (www.atlasole.gse.it)
Energy consumption of the Municipality by energy carrier	Municipality's bills
	Municipality's bills
	Municipality's data
	Municipality's data
Waste production and separate collection	Municipality's data
Supporting data	Statistics (www.istat.it)
	Regional registry (www.curit.it)
	Statistics (www.aci.it)
	Statistics (www.aci.it)

Table 2

Emission Factors for each energy carrier. Source: (IPCC, 2006). *Source (Italian Ministry of Environment, 2012).

Energy carrier sector	EF (tCO ₂ EQ/MWh)
Natural Gas	0.202
LPG	0.227
Petrol	0.249
Fuel Oil	0.264
Diesel	0.267
Biomass	0.403
Electricity*	0.531

- AE is the avoided GHG emissions (tCO₂EQ);
- C is the annual installed capacity (MW);
- 1100 is the operative hours of a plant in 1 year;
- 0.531 is the Emission Factor for the electricity production (tCO₂EQ/MWh) - Table 2

The emission factor considered is based on life cycle assessment approach, namely it takes into account the embodied CO₂ emissions in the PV production.

2.1.2. GHG emissions related to waste generation and recycling

Limiting the accounting to energy consumptions might be not enough to estimate all GHG emissions at Municipal level. For example, both goods “consumed” by citizens and waste flows related to the end of life of goods are as well causing GHG emissions. Regarding the waste-related emissions, those are linked to both waste generation and waste management system (e.g. incineration, landfill). Potential benefits may be accounted for in relation to separated waste collection, e.g. when considering that recycling may lead to reduce the use of virgin materials.

In order to indirectly account for the emissions associated to the overall consumption of goods within the area of the Municipality, the related GHG emissions can be estimated on the basis of the waste produced within the Municipality. According to a study conducted by (APAT, 2007), the average emission factor is 2.2 kg of CO₂eq per kg of waste. This is of course a very coarse estimation. However, the value may be used for a screening evaluation of the emission related to goods consumption.

Besides, adopting life cycle thinking as leading principle, separated collection of waste, and consequent recycling, may imply less GHG emissions from raw material extraction. Therefore, a share of GHG emissions can be considered as avoided due to the separate collection and recycling of waste (Weitz et al., 2002). Emission factors to calculate avoided emissions related to different materials and taken into account for the case studies are shown in Table 3.

2.1.3. GHG emissions due to specific areas of consumption, e.g. the contribution of food consumption

Households are responsible of GHG emissions in relation to three main areas of consumption: housing, mobility and food (EEA, 2012). Therefore, in the present study, a proposal to integrate the evaluation of emissions associated to food consumption in the calculation of the baseline is put forward. A recent study (Notarnicola et al., 2017) at European level has assessed GHG emissions related to a basket of 17 food products representing the average food consumption of a European citizen in one year. The calculation of the GHG emissions has been performed applying life cycle assessment from ‘cradle to grave’. The results reveal that food consumption of an average European citizen is responsible for 1.4 ton of CO₂eq in one year. Results are referring to the baseline year adopted in the above-cited study (2010). Multiplying the emission per capita with the population of each local authority allows

Table 3

Emission factors for different recycled materials. Source: (US EPA, 2006). * Source: (COBAT, 2004)..

Material	EF (tCO ₂ EQ/t _{waste})
Biowaste	0.181
Glass	0.254
Paper	3.211
Cardboard	2.821
Plastic	1.352
Wood	2.322
Steel	1.624
Aluminum	12.311
Mixed metals	4.736
Copper	4.463
Lead*	0.89
Tires	0.51
Computers and electronic appl.	5.427
Refrigerators	2.75
Lubricating oils	0.125
Inert	0.01

reporting an estimate of possible contribution of food consumption to the overall emissions.

2.1.4. GHG emissions in local land use planning

The Paris Agreement commits the Parties to achieve a balance between emissions and uptake of greenhouse gases. Therefore, terrestrial carbon sinks, as forests, will have an increasingly important role to develop climate actions. A robust accounting method at local level should take into account how the land use sector affects the carbon balance.

As a preliminary proposal (Sala et al., 2009), developed a methodology suitable at local scale, including the accounting derived from CO₂ uptake from green areas, on the basis of their type of vegetation and extension. The absorption capacity has been estimated on the basis of different land coverage. To associate each land cover to an indicative value of CO₂ uptake, studies and parameters related to Italian geographic and climatic conditions were considered (Pennati et al., 2009). The data used for the calculation are reported in Table 4.

2.2. Case study

To illustrate the methodology, 16 municipalities -which were signatories of the CoM- have been selected. The municipalities are all located in Northern Italy, in Lombardia region: Vimercate, Agrate Brianza, Burago di Molgora, Bellusco, Mezzago, Sulbiate, Cornate d’Adda, Carnate, Ronco Briantino, Pessano con Bornago, Bussero, Uboldo, Molteno, Bosisio Parini, Annone, and Ornago. The municipalities are small-medium size towns (maximum number of inhabitants is 25758 in Vimercate, minimum in Annone 2292). Since

Table 4

CO₂ uptake coefficient used for local land use planning.

Land cover	Uptake coefficient (tCO ₂ ha ⁻¹ year ⁻¹)	Source
Cropland	0	(Bongen, 2003)
Poplar	16.05	(Tedeschi et al., 2005)
Grassland	5.12	(Emmerich, 2003)
Broad-leaves forest	34.55	(De Lucia et al., 2007)
Coniferous forest	40.88	(De Lucia et al., 2007)
Mixed forest	24.19	(De Lucia et al., 2007)
Natural vegetation	2.93	(Emmerich, 2003)
Barren areas	0	
Lakes and rivers	10.46	(Emmerich, 2003)
Built up land	0	

a large share of COM signatories are small-medium size towns with less than 50000 inhabitants, the selected case studies are representative of the most frequent European situation. High population densities characterize the biggest municipalities (> 1000 inhabitants/kmq), and the whole area had an increasing urban development from the sixties of the previous century. Industries and manufacturing are the main sectors of activities, and in five municipalities out of 16 (Agrate Brianza, Annone, Bosisio Parini, Ornago, and Uboldo) the industrial sector is particularly important. As mentioned above, the reference year selected for the BEI was the 2005.

Due to data availability, the approach proposed in section 2.1.4 has been applied to another municipality (Carugate) belonging to the same geographical area.

3. Results

An overview of the results is reported in the following sections, including: the baseline, and the results related to waste generation and recycling, to food consumption, and to land use at local scale.

3.1. Baseline emission inventories and emissions from waste generation and recycling

According to the methodology proposed by the CoM for the BEI, data for each municipality have been collected and calculated in terms of CO₂eq. Fig. 2 shows the emissions of the Municipalities. In principle, emission are correlated with the population size: municipalities more populated (as Vimercate and Agrate Brianza) have higher emissions in absolute terms. GHG emissions directly related to the Municipality activities (namely consumption of the local authority) cover a small share of the total value. However, as mentioned above, the Covenant of Mayor required the explicit inclusion of public buildings and premises, so to represent a model for the other involved actors.

For the analysed cases, the biggest contribution to GHG emissions comes from the consumption of the natural gas in the household sector. For example, as shown in Fig. 3, in the Municipality of Vimercate household consumptions cover about 54% of the energy consumptions, and natural gas consumption represents about 63% of the overall energy consumptions. In some cases, as for Agrate Brianza, the electricity consumption play an important role in the overall GHG emissions. In the specific case, this depends mainly on the industries present in the territory and among those not included in Emission Trading Scheme (non-ETS) (Fig. 3).

The GHG Emissions of the assessed municipalities vary from about 4.5 tons per inhabitant to 11.5 tons per inhabitant. Higher values mainly depend on the presence of non-ETS industries and tertiary sector, both related to high electricity consumptions. The scatter plot between the share of GHG Emissions from electricity and the GHG Emissions per inhabitant is shown in Fig. 4. The 16 municipalities show a positive linear correlation of the two variables with a coefficient of determination of 0.25. The different structure of consumption as well as the different socio-economic activities present in the municipalities explain the low correlation.

The CoM initiative directly involves the administrations of different Municipalities, including commitments to be taken on e.g. municipality's building stock and, hence, specific data to be collected regarding the public building stock. The relative share of the emission is on average very low (few percentage points). However, the specific accounting reflects the need of acting as example for improving the reporting from other sectors.

In Cerutti et al. (2013) five years of CoM were assessed, and main statistics about the submitted SEAPs were given. The majority of the signatories had chosen as baseline year the 2005 (or the 2007),

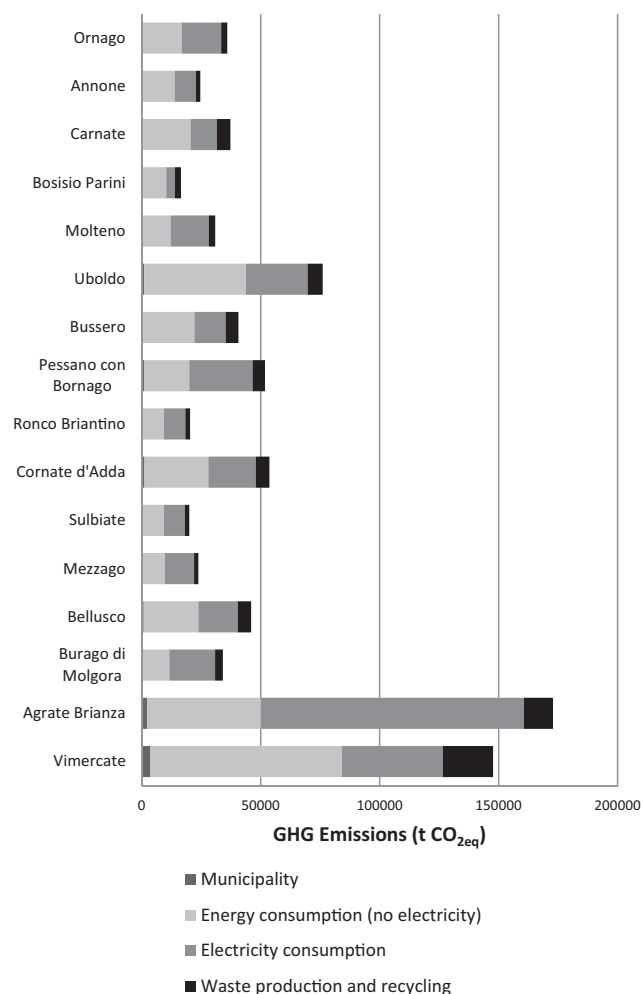


Fig. 2. GHG Emissions from energy consumptions and waste management in t of CO₂eq by Municipality and Emission source (baseline year 2005).

despite the Guidelines recommend the 1990. Probably, as for the presented case studies, the lack of data did not allow choosing the 1990, and the year 2005 has been chosen as baseline also for the legally binding targets of the Europe 2020 strategy (for the Non-ETS sectors). The main figures of the case study are confirmed by the five years assessment: i) the residential sector plays the main role (with some exceptions for Spain, Portugal and France); ii) the emissions from the Municipality's facilities represent only about the 2%, but those should be separately accounted because the municipal administration has a driving role in the project, and so specific action to reduce GHG emissions from Municipality's activity should be planned within the CoM.

Emissions due to waste generation and recycling range between 7% (Agrate Brianza and Ornago) and 15.6% (Bosisio Parini). Notwithstanding the relative limited share of this emission compared to the overall BEI, there is a potential for increasing benefits associated to appropriate waste prevention and recycling strategies at local scale.

3.2. GHG emissions from food consumption

Regarding the inclusion of food consumption, at the moment, regional or local specific data are not available. Hence, the average European figure per capita (1.40 ton CO₂eq) has been used in order to add the food consumption component to the different municipalities, multiplying the emission factor of the average food

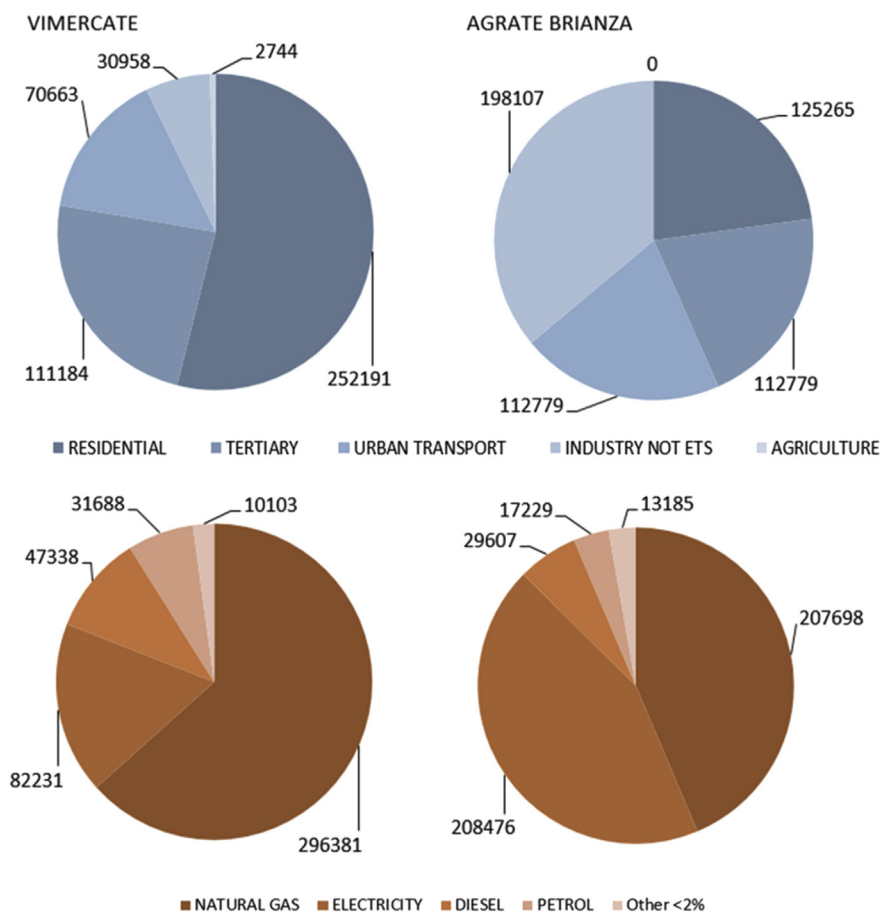


Fig. 3. Energy consumption in MWh by sector and by vector of Vimercate and Agrate Brianza for 2005.

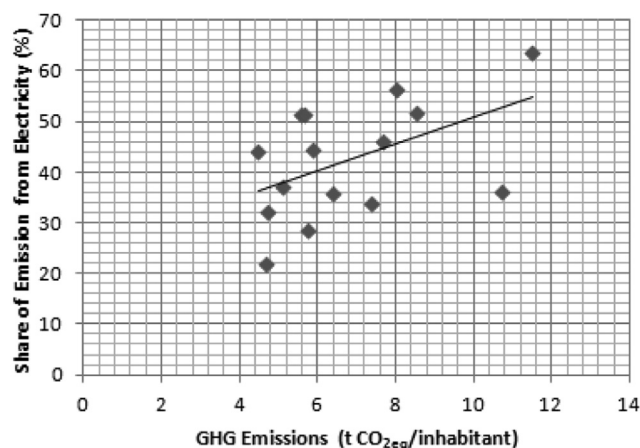


Fig. 4. Correlation between GHG Emissions and share of emission due to electricity consumption.

consumption of a EU citizen by the population of the different municipalities. Results in Fig. 5 show that adding the emissions due to food consumption increase the total municipal emission in a range between 13.1% (Annone) and 31.3% (Sulbiate), with an average of 22.6% for the selected case studies. This means that household consumption could denote for a significant portion of municipal emissions that future and enhanced methodologies should be taken into account. Anyway, it is important to remark

that the emission factor considered represents an average European situation, at the moment are linearly correlated with the population size, and further studies should be necessary to capture the specific reality of local food consumptions.

3.3. Local land use planning and the role of urban forests

The calculation of the CO₂ uptake following the methodology described in 2.1.4 was carried out considering the land use map provided by Lombardy Region for the territory of the Municipality of Carugate, by allocating different CO₂ uptake coefficients related to different land covers. For the Municipality of Carugate, the annual uptake of CO₂ from local land uses is 358 t, which balances only 0.2% of the emitted CO₂. However in Municipalities with higher shares of forested areas, the uptake can significantly affect the local carbon balance, and climate actions which include the increase of green areas such as urban forests, or a better management of those, can be properly accounted for in terms of their potential to uptake CO₂ as well as to address local climate challenges, related to e.g. mitigation and adaptation.

4. Discussion

A screening methodology to extended GHG emissions at municipal level has been developed in order to further support strategic local policies when planning GHG reductions. The methodology relies on simple equations to calculate GHG emissions capitalising available data and information, and being suitable to be adopted by small local authorities (e.g. when more accurate

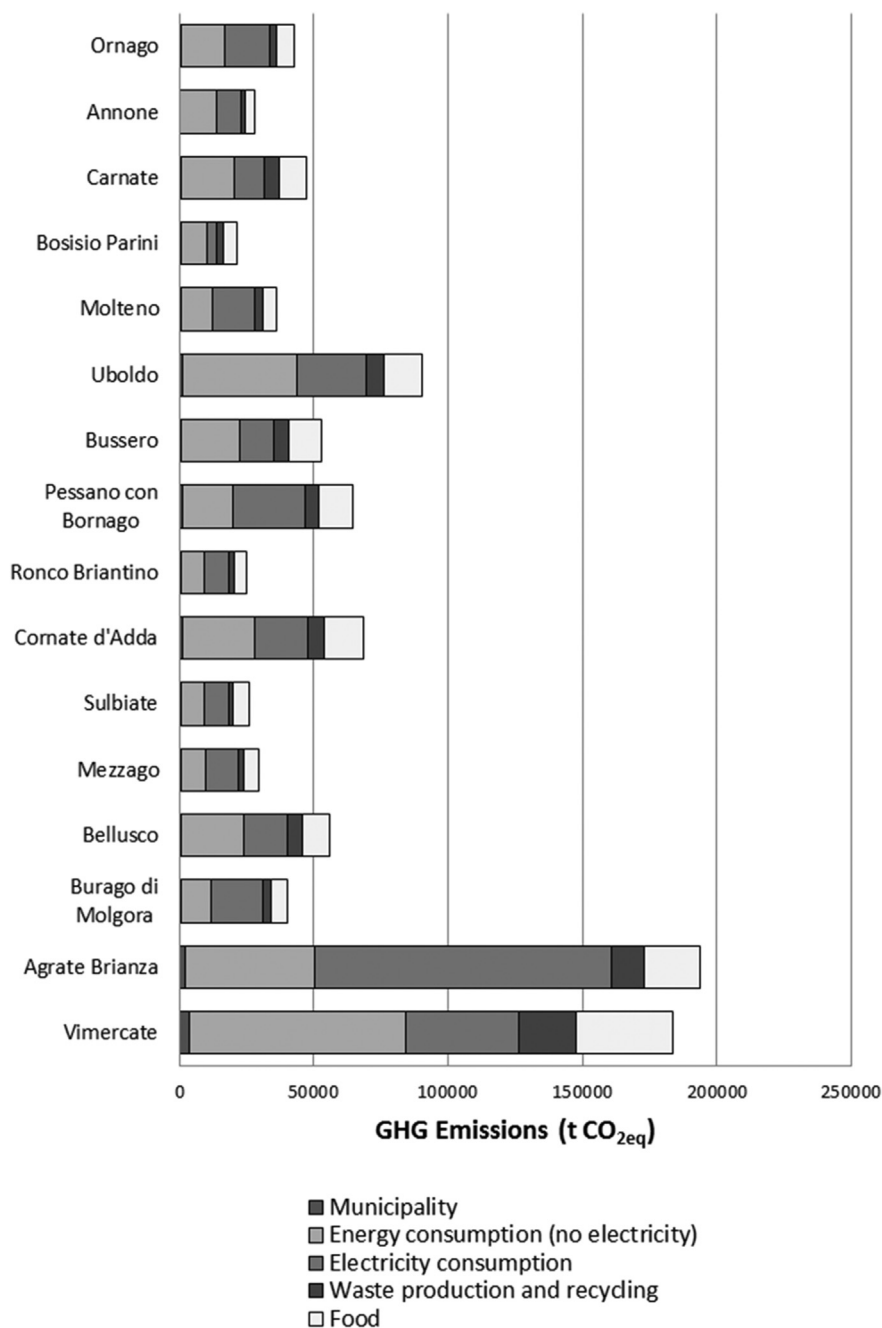


Fig. 5. GHG emissions in t of CO_{2eq} by Municipality and Emission source, including an estimation of emissions coming from municipal food consumption (baseline year 2005).

analysis, or local data collections are not feasible). The methodology, devised to be specific for the Lombardy Region, may be further developed in future and adapted to be applicable to other areas. Moreover, context-specific studies may be used to change the emission factors, according to local conditions (e.g. local waste management systems, different food consumption patterns etc).

According to Kona et al. (2015), the average GHG emissions per capita for signatories of CoM is 5.44 tCO_{2eq}/cap, while the EU-28 average for GHG Emission in CoM sectors (Non-ETS and Public electricity and heat production) is 8.7 (tCO_{2eq}/cap), considering 2005 as reference year. The average value of GHG emissions of Italian CoM signatories equals to 4.68 tCO_{2eq} (Kona et al., 2015). This value is in line with the selected case studies, which present a value of 4.6 tCO_{2eq}.

Despite this alignment, the comparison of emissions profile of the selected signatories provide some food for thoughts in terms of accounting methods and approaches. In general, this comparison is relatively complex, as the scientific debate of urban GHG emissions accounting and comparison is open, and homogenous global guidelines are still missing. Ibrahim (2015) used the municipal GHG emissions data for New York City to evaluate the GHG inventory of the city, using four protocols (ICLEI, 2009; Bertoldi et al., 2010; Schmitz et al., 2004; ISO, 2006), obtaining four different emission profiles. Moreover, even when the accounting methodology is the same, cities differ in terms of size, history, socio-economic, geographical and climate context, etc. and this causes that a horizontal comparison of their emissions is not possible.

Hence, the selected case studies offer a good starting point, as

they belong to the same climate and geographical context, and they share common urban patterns. Comparing the emissions generated per inhabitant with the emissions sources, it is possible to notice that the territorial approach of the CoM is more efficacious for municipalities with a prevalence of the residential sector or with a mixed industrial/residential vocation. Indeed, in these cases the emissions per capita including and excluding the industry non-ETS vary of about 27%, while in the case of industrial towns this percentage is much higher (60%).

Based on the results, two considerations are possible: i) a territorial approach can penalize urban contexts that are net producers in terms of emissions, i.e. where a high share of the activities in the territory generate products that are consumed elsewhere; ii) the accounting and identification of industrial sources could be the basis to promote exchange of best practices among private actors.

Accounting for the avoided emissions due to waste recycling allow highlighting the most effective municipalities in terms of waste collection and management. Including the full waste cycle (generation, management and recycling) helps the municipalities knowing, managing and reducing environmental burdens associated to waste production. Improved and integrated policies for waste prevention and reduction, e.g. in line with a circular economy approach, are the desired final output.

Regarding the accounting of emission associated to food consumption, they may play a relevant role in defying GHG reduction policies that increase awareness of citizens regarding their consumption patterns, in an holistic manner.

For what concerns the appropriate accounting of land use implications to CO₂ balance at municipal level, a more detailed methodology shall be developed in future, e.g. taking into account carbon uptake of urban forests. In fact, more detailed evaluation of the factors determining the possible uptake should be performed. Nevertheless, the application of the methodology may help local decision makers understanding to which extent local emissions are relying on CO₂ uptake happening beyond municipalities boundaries and helping understanding the importance of the integration of land use planning and climate actions. Therefore, further research should be dedicated to integrate accounting methods of land use related emissions and removals at local scale in a cost-effective way, addressing the subsequent potential climate effects.

Regarding the application of the methodology to the case studies, the main challenge consisted in the data collection. In fact, some of the data were not available from Regional or a National database. Therefore, the direct involvement of the Municipalities was crucial. Moreover, over the years, CoM signatories have been asked to monitor the achievement of their target in terms of GHG reduction. Every second year, signatories should submit a monitoring report of the implementation of the actions (Kona et al., 2015). Besides the BEI calculation, for the selected case studies, a toolkit supporting the emissions' monitoring was developed and provided to the Municipalities in order to collect data for reviewing their baseline, updating the emission inventory, and for monitoring the their action plan. The aim of the toolkit was to support data gathering and management and to allow every Municipality easily monitoring and updating their action plan on the basis of the available data. In this way, municipalities could track their progresses over the time more quickly and more efficiently. The toolkit has been provided as joined MS Excel sheets' collections to make it easy-to-use by the officers of all the municipalities. The toolkit is divided in five core sectors that reflect data inventory: i) Municipal; ii) Waste; iii) SIRENA; iv) MActions; v) Support. An overview of the whole toolkit and its sections is given in Table 5.

Within the tool, the possibility of displaying aggregated and disaggregated data and results for each sector could provide a more effective support to the monitoring process for different audiences,

Table 5

Overview of the Toolkit "MONITORAGGIO" provided to the 16 municipalities involved in the study.

Tool name	Aim
MEI/MUNICIPAL	It calculates the GHG emissions related to the activities of the Municipality (buildings, street lighting, and cars of the Municipality).
MEI/WASTE	It calculates GHG emissions from waste production and avoided GHG emission from recycling.
MEI/SIRENA	It automatically calculates the Emission Inventory from SIRENA data and MEI/MUNICIPAL and MEI/WASTE outputs.
MACTIONS	It monitors the SEAP's actions through a sheet for every action. It calculates, when it is possible, the avoided emissions due to the action.
SUPPORT	Framework for data collection not related to quantifiable emissions/actions.

even with a low level of the expertise in the field.

5. Conclusions

The Covenant of Mayors initiative has been very successful in Europe (European Union, 2017). Joining the Covenant of Mayors is strategic for local administration towards GHG emission reduction.

Joining the CoM is a formal act, and this can stimulate innovative policies at local scale. It is a good framework to promote effective multi-level governance in relation to climate change policy implementation.

The approach proposed by the CoM is based on analyzing the final consumptions and on defining voluntary actions to reduce the emissions. It considers different sectors, the inclusion of local generation of energy, but the mandatory reduction target is on the total GHG emissions. The proposed extended method makes a step forward by including aspects related to the waste cycle, the food consumption, and the local land use. Moreover, a joint toolkit for monitoring allows a consistent comparison of several municipalities located in the same areas and, thus, facilitates the exchange of good practices in the long run by accounting for specific climate actions at local level.

Following the development in terms of global commitments, and taking into account the increasingly important role of regions, cities and local authorities, local climate and energy policies should be based not only on the reduction of GHG emissions, but also on developing bioeconomy value cycles and efficient productions, distributed energy generations, and on dropping the energy demand through the increase of energy efficiency and more responsible consumptions. The proposed approach complement the current accounting system and can be further developed for being a cornerstone of local climate and energy actions.

The study highlighted the importance of a cross-policies approach to emission accounting, including e.g.: energy policies, waste policies, sustainable production and consumption policies, and local land use planning.

For the analysed case studies, the biggest contribution to GHG emissions comes from the consumption of the natural gas and electricity by the household sector. Emissions from waste generation play a minor role, but the inclusion of avoided emissions coming from recycling highlights the reduction potential if an appropriate waste management system is in place. The link with local policies for circular economy is straightforward. Besides, consumption patterns may play a relevant role. Assessing the food consumption GHG emissions on top of those due to other drivers, the total municipal emission change, increasing for an average of 22.6% for the selected case studies. Finally, the land use management should be included in the assessment, being crucial not only

for the emissions uptake but also for climate mitigation and adaptation. The proposed approach to GHG accounting may help identifying a wider set of climate actions to be implemented by the local authorities. Adopting consumption-based approaches can significantly help widening the number of actions a local authority may envisage to reduce environmental burdens, locally and globally.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jclepro.2017.12.055>.

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